FORESTRY

CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

Canada

BC

FRDA Report 169

Microclimate Monitoring in a Study of NSR Backlog Rehabilitation in the Boreal Region of British Columbia

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October 1991

CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

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93-01226/

Funding for this publication was provided by the Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II – a four year (1991-95) $200 million program cost-shared equally by the federal and provincial governments.

Canadian Cataloguing in Publication Data

Letchford, T.
Microclimate monitoring in a study of NSR backlog rehabilitation in the boreal region of British Columbia

(FRDA report, ISSN 0835-0752 ; 169)

"Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II."
On cover: Canada-BC Forest Resource Development Agreement.
Co-published by B.C. Ministry of Forests.
Includes bibliographical references: p.
ISBN 0-7726-1439-3

1. Forest microclimatology - British Columbia - Peace River (Regional District). 2. Forest site quality - British Columbia - Peace River (Regional District). 3. White spruce - British Columbia - Peace River (Regional District) - Seedlings. 4. Lodgepole pine - British Columbia - Peace River (Regional District) - Seedlings. I. Canada. Forestry Canada. II. Canada-British Columbia Forest Resource Development Agreement. III. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II. IV. British Columbia. Ministry of Forests. V. Title. VI. Series

SD397.C7L47 1991 634.9'752565 C91-092343-4

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This is a joint publication of Forestry Canada and the British Columbia Ministry of Forests.

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ABSTRACT

Twelve combinations of mechanical site preparation and herbicide levels were tested in an NSR (not satisfactorily restocked) backlog area in the boreal region of British Columbia. White spruce and lodgepole pine 1+0 plug stock were spring planted and the microclimate monitored. This report discusses 4-year microclimate data, installation and maintenance of the monitoring system, seedling survival and growth, and vegetation responses. Results showed that plowing was best for increasing soil temperature, especially in combination with herbicide; winter shearblading was poorest. Nearly 80% of spruce and 30% of pine were injured between fall 1985 and spring 1986. Site preparation affected seedling growth, with the plowing treatment performing the best. Competing aspen was controlled best with glyphosate applied two growing seasons after mechanical site preparation. Reed grass competition was reduced most by plowing.

ACKNOWLEDGEMENTS

I wish to acknowledge the valuable influence of Dr. Dave Spittlehouse of the Research Branch. Over several seasons of working in conjunction with him, installing, programming and debugging micro-meteorological installations, I feel I have absorbed some of his considerable expertise. His continued guidance is appreciated.

The contributions of Dr. Dale Draper, Bonnie Hooge, and Rick Fahlman, all of the B.C. Forest Service, and Stu McArthur, formerly of the Forest Service, are recognized and appreciated.

Les Herring of the Prince George Region, Forest Sciences, who is the principal author of FRDA Project 1.02, is acknowledged for his consultations, interpretations and contributions to this report. The environmental monitoring program is but one component of his complex experiment in the rehabilitation of hardwood stands.

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1 INTRODUCTION

In 1984/85, FRDA Project 1.02 (EP 986) was established on a site near Dawson Creek to test and demonstrate site rehabilitation alternatives in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone of British Columbia. The working plan, "Assessment of Treatment Options for Rehabilitation of NSR Backlog in the Boreal Region of B.C." (Herring *et al.* 1985) provided for the monitoring of soil temperature and moisture regimes under the various treatments tested by the project. This report summarizes 4-year microclimate measurements, and focuses on the 3-year seedling response data.

1.1 Project Overview

With potentially 2 million ha of "not sufficiently restocked" (NSR) land in the Prince George Forest Region, and approximately 0.58 million ha of backlog land in the Dawson Creek and Fort St. John Forest Districts combined,[1] mechanical site preparation and herbicide treatment combinations are needed to reduce the NSR area. Results from EP 986 are relevant to much of this area, which falls in the Alberta Plateau.[2]

With the advent of a hardwood industry in Dawson Creek in 1986, the Ministry of Forests' commitment to convert NSR to conifers was tempered. A government and industry committee recommended in 1986 that established young aspen stands be left to grow while uneconomic aspen stands be converted to conifers. Thus, the requirements of both hardwood and softwood users in the Peace River region were acknowledged, and the NSR conversion practices tested in Project 1.02 continued to be relevant.

The experimental layout is a completely randomized, split-plot design with three replicates. Herbicide is the main plot factor, and mechanical site preparation (MSP) a sub-plot factor. Three levels of herbicide over four MSP levels provide 12 treatments (Table 1a) referred to as "panels" in this report. Three silvicultural regimes, distinguished by the level and/or timing of herbicide application, are being tested (Table 1b). These regimes are: MSP alone; MSP followed by herbicide, then planting; and MSP followed by planting and then chemical brushing and weeding. Two 1+0 stock types (white spruce PSB 313 and lodgepole pine PSB 211) are planted in 10 five-seedling rows at a 3-m spacing. The entire layout was initiated in 1984 (phase 1) and repeated in 1985 (phase 2) to account for annual variation of climate and stock quality. Only phase 1 was monitored for microclimate.

1.2 Site Description

The study site is located 50 km northwest of Dawson Creek and 40 km southwest of Fort St. John (Figure 1) 5.5 km along the Stewart Lake Forest Road, 55°54' N, 121°00' W, at 800 ±15 m elevation. The area lies in the upland of the Alberta Plateau, an extension of the Interior Plains. The upland is a flat and gently rolling unit which has been partly dissected. Glacial deposits are primarily lacustrine or till in the vicinity of the site.

Soils in the area have been classified as Moberly brunisolic grey luvisols derived from Cordilleran tills.[3] The soil phase is predominantly sandy to silty loam with minor inclusions of lithic and gravelly phases. The soils are well to moderately well drained and moderately to slowly pervious.

The site is within the Boreal White and Black Spruce (BWBS) biogeoclimatic zone. Forest fires are a frequent and integral part of the ecosystem and maintain most of the forests in various successional stages (Annas 1983). The climate is continental, characterized by long, cold winters and short, warm summers. During the summer months, the site receives a relatively high number of sunshine hours as well as the annual maximum precipitation. The climate of Fort St. John is characteristic of the region (Figure 2).

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[1] Przeczek, J.E. 1984. Not satisfactorily restocked (NSR) lands in the Prince George Forest Region. A problem analysis. B.C. Min. For., Prince George For. Reg. Unpublished report.

[2] Herring, L.J., R.A. Fahlman, and R.A. Letchford. 1985. Assessment of treatment options for rehabilitation of NSR backlog in the Boreal Region of B.C. Project workplan. B.C. Min. For., Research Br., Victoria, B.C. Unpublished report.

[3] _____. 1986. Assessment of treatment options for rehabilitation of NSR backlog in the Boreal Region of B.C. Establishment report, Experimental Phase 1. B.C. Min. For., Research Br., Victoria, B.C. Unpublished report.

Current vegetation in the area reflects recent events. Until 1950, the general stand type was pine-spruce-poplar mixed-wood. Since then lodgepole pine has been used by portable tie-mill operations, large-diameter spruce has also been removed. Most recently, several wildfires have swept the area, the latest and largest occurring in 1971. A dense aspen/balsam poplar sapling cover (20 000 sph) and reed grass result in serious competition to planted conifer seedlings.

TABLE 1a. The split-plot design of FRDA Project 1.02

Main plot factor: three levels of herbicide using glyphosate (Roundup®)
R1: no herbicide application.
R2: glyphosate applied one growing season following mechanical site preparation.
R3: glyphosate applied two growing seasons following mechanical site preparation.
Sub-plot factor: four levels of mechanical site preparation
T00: fall brush clearing with a modified piling blade.
T01: fall brush clearing followed by cultivation with a land-breaking plow.
T02: fall brush clearing followed by cultivation with a land-breaking disk.
T03: winter shear cutting followed by brush piling.

1b. The schedule of herbicide applications and planting, resulting in three silvicultural regimes. All mechanical site preparation took place in the fall of 1984.

Year	Regime 1	Regime 2	Regime 3
1985	plant	herbicide	plant
1986		plant	herbicide

1.3 Site Weather

Weather data for the period May 1977 to October 1984 were available from a British Columbia Ministry of Environment meteorological station at Sunset Prairie, 10 km northeast of the site (55°55' N, 120°5' W, 835 m). Mean temperature and precipitation values on a monthly basis over the 8-year period were calculated and are presented in Figure 3. This is a short term over which to generalize climate, but it indicates that Sunset Prairie was drier and cooler than Fort St. John. Annual precipitation is 450 mm at Fort St. John and 372 mm at Sunset Prairie. Three-quarters of Sunset Prairie's precipitation (268 mm) is received from May to September. Mean temperatures are below freezing November to March and above 10°C June to August. Extreme maximum (+33°C) and minimum (-42°C) occurred in August and February, respectively, indicating the wide temperature range encountered in the area. July is the only month without frost, although Dawson Creek has experienced frost in all months. Conditions at the research site are assumed to be very similar to these locations because of their proximity.

1.4 Project Objectives

Data from the environmental monitoring component of Project 1.02 will help explain seedling and vegetation growth in the boreal region of British Columbia. The objectives of the environmental monitoring program were: 1) to characterize the 12 treatment panels by soil moisture and temperature; and 2) to monitor local weather conditions.

FIGURE 1. Research site location in the Peace River region of British Columbia.

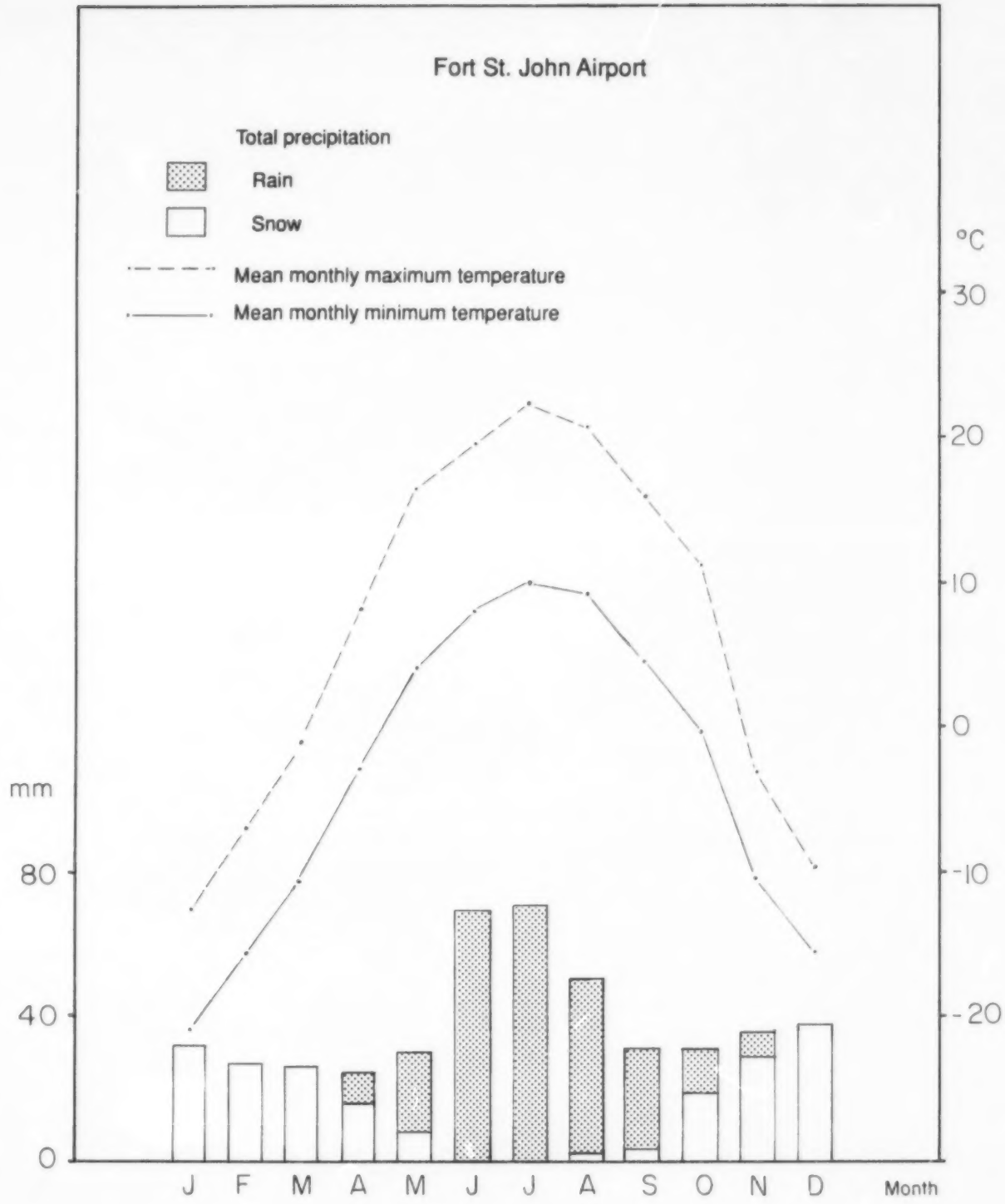


FIGURE 2. Fort St. John annual precipitation and temperature graphs based on a 28-year record (from Chilton 1981).

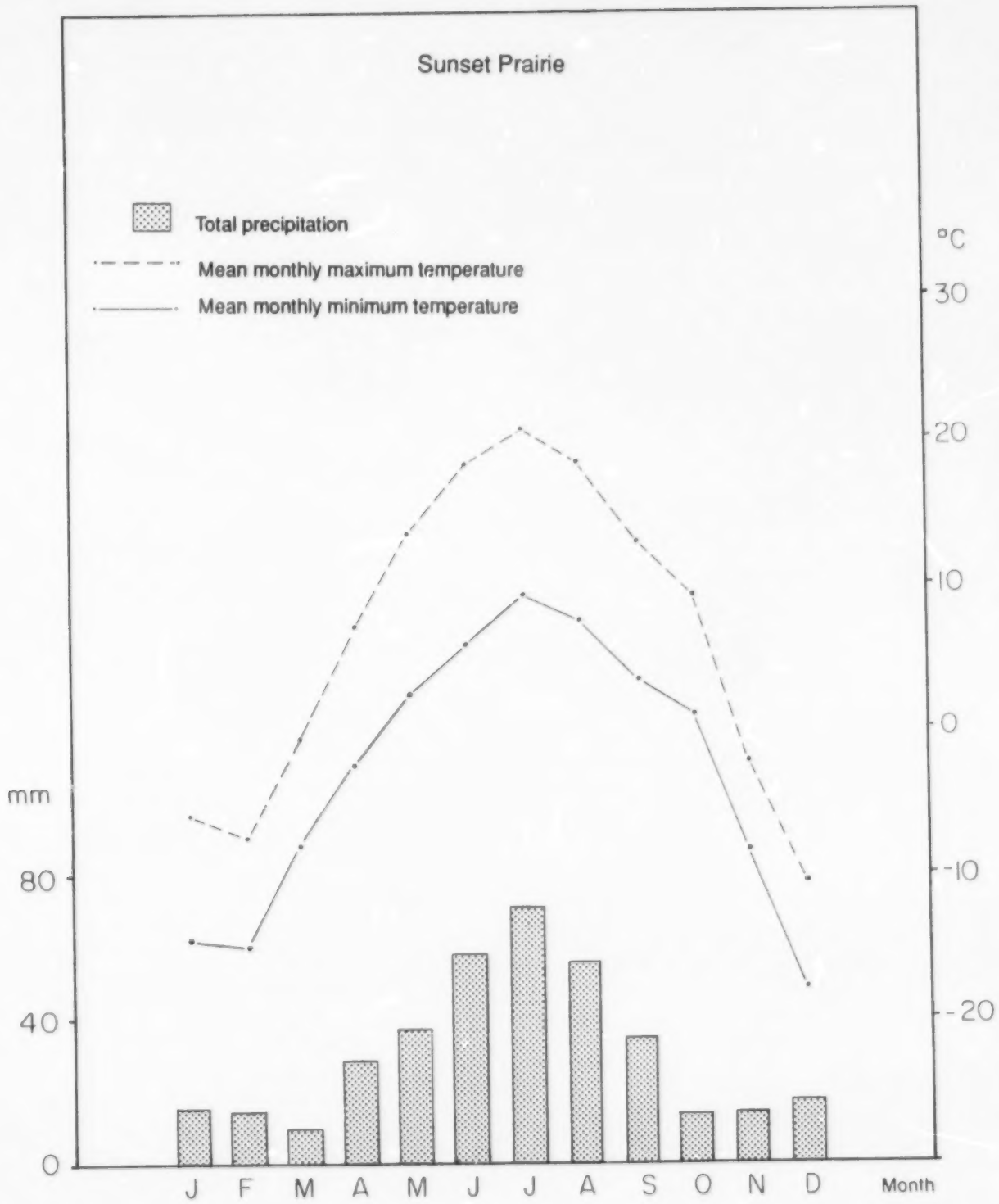


FIGURE 3. Sunset Prairie annual precipitation and air temperature graphs based on a recent 8-year record.

2 MATERIALS AND METHODS

A system of electronic data loggers and sensors was used to collect microclimate data. Site development work was completed by April 1985 and planting proceeded on May 29. A network of sensors and data loggers was installed and operational in one replicate of regimes 1 and 2 by May 24. Regime 3 was added to the network in June 1986. Occasional estimates of soil bulk density and moisture were made. Bulk density samples were taken with the use of a slide hammer and steel sleeve (67 x 98 mm) centred at 15 cm deep in mineral soil. The same equipment was used to sample for soil moisture content from 0 to 7 cm deep in mineral soil. Monitoring equipment was removed in October 1989 after the fifth growing season.

2.1 System Design

Phase 1 of Project 1.02 extends over approximately 12 ha of level to slightly sloping land. One replicate of the main plot factor over the four site preparation treatments was arbitrarily chosen for monitoring (Figure 4). These 12 treatment panels were labelled A through L. Three microsites were systematically selected within each of the 30 x 100 m panels. At each microsite, temperature sensors were installed at +16, +1, -5, -15, and -30 cm. A pair of gypsum moisture blocks were installed at -15 cm. Figure 5 shows sensor placement relative to seedling dimensions. Sensors were monitored by a system of four data loggers and four multiplexers. This sampling technique resulted in pseudo-replication, but the sampled area is thought to be representative of the entire site.

A meteorological station was located between panels G and H. It included an anemometer at 2.5 m and a tipping bucket rain gauge. A humidity sensor, air temperature sensor, and long-term thermograph were mounted at 1.5 m in a Stevenson's screen. A quantum sensor was placed at 1.5 m between panels C and D. Campbell Scientific, Inc. (CSI) model 21X data loggers and AM32 multiplexers were used to monitor sensors. The selection was based on the experience of ministry personnel familiar with the equipment.

Temperature sensors were constructed similar to CSI specifications for the 107 thermistor probe. Thermistors were potted in a two-part epoxy resin. They were calibrated against a certified mercury thermometer at three points: 0, 20 and 30°C. Single regression equations providing multiplier and offset values were calculated for each batch. The departure of individual predicted values from actual values indicated that most sensors were accurate to ±0.2°C. A few were ±0.3°C. These results were within the CSI stated error and it is believed their performance could be safely extrapolated over the wider -33 to +48°C specified by CSI. A more conservative accuracy of ±0.5°C was adopted. It is important to note that the probes underestimate temperature below -33°C. At -40°C this error is greater than 1°C. Below this the probe is unusable.

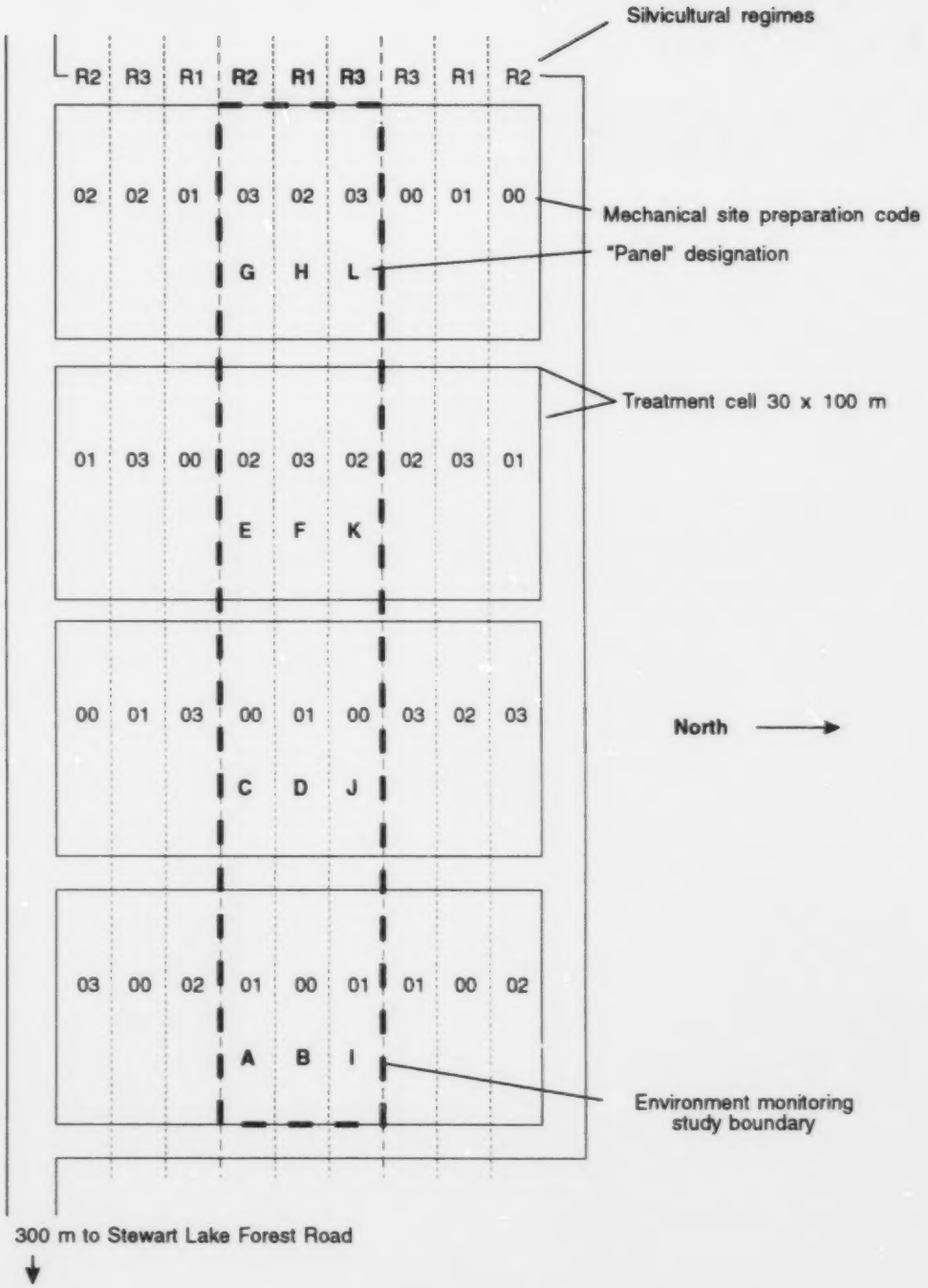
A sub-sample of moisture blocks was calibrated by Soilcon Labs of Vancouver, B.C. Results indicated the stated manufacturer's calibration curve was correct.

2.2 Equipment Installation and Maintenance

Each microsite had seven sensors, with up to five monitored at one time. Figure 6 shows sensor position relative to seedling dimensions. The microsites represented a plantable spot but did not include a seedling. Sensor depth and height were measured from the local mineral soil surface, which coincided with seedling planting depth and depended on the mechanical site preparation. Sensors and data loggers were installed on three occasions: spring 1985, fall 1985, and spring 1986.

2.2.1 Spring 1985

Most of the program's equipment was installed on May 23–24, 1985. One hundred and twenty temperature probes, 48 soil moisture blocks, 4 data loggers, 2 multiplexers and the meteorological station were positioned in the 8 panels of regimes 1 and 2. Some areas of frozen ground were encountered, and saturated soil and standing water were occasionally a hindrance.


Silvicultural regimes
R2 R3 R1 R2 R1 R3 R3 R1 R2
02 02 01 03 02 03 00 01 00
G H L
Mechanical site preparation code
"Panel" designation
Treatment cell 30 x 100 m
01 03 00 02 03 02 02 03 01
E F K
00 01 03 00 01 00 03 02 03
C D J
North
03 00 02 01 00 01 01 00 02
A B I
Environment monitoring study boundary
300 m to Stewart Lake Forest Road

Silvicultual regimes (all with mechanical site preparation in 1984)

R1	plant 1985
R2	herbicide 1985, plant 1986
R3	plant 1985, herbicide 1986

Mechanical site preparation treatments

00	Beal's rake
01	Beal's rake and breaking plow
02	Beal's rake and rome disk
03	winter shear blade

FIGURE 4. Research site layout showing treatment assignments and panels that were monitored.

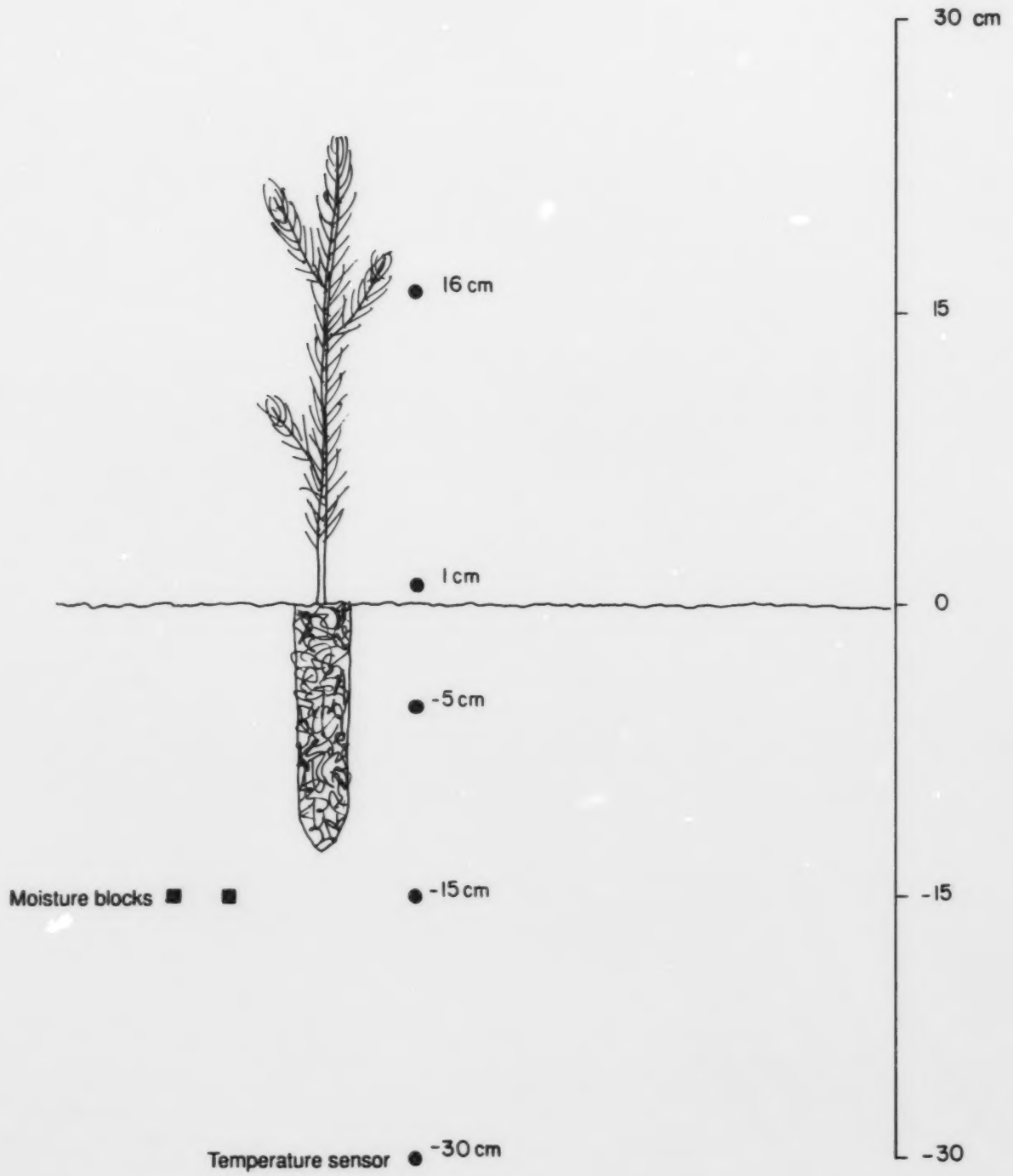


FIGURE 5. Sensor placement relative to a 1+0 white spruce seedling after one growing season.

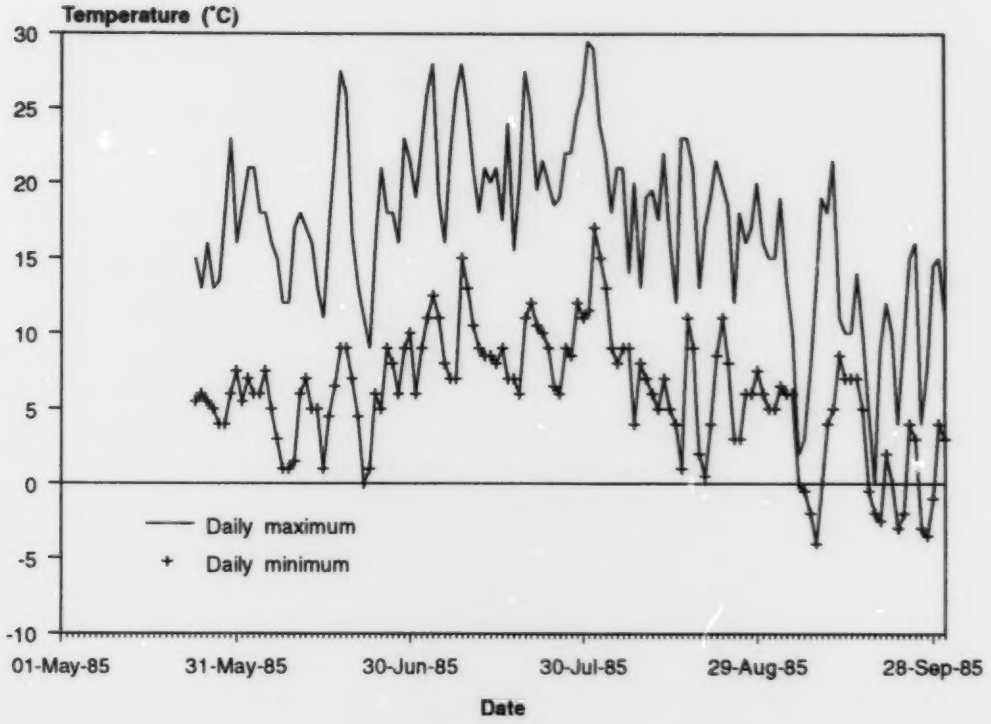


FIGURE 6. Daily maximum and minimum air temperatures at 1.5 m during the summer of 1985.

Microsite selection was done on site; the approximate locations of the data loggers, multiplexers, and weather station was predetermined. The distance between microsite and monitoring equipment was restricted to 25 m for practical purposes. The reduced area for sampling was equivalent in all panels. Three randomly chosen co-ordinates were systematically applied to each of the eight panels to select microsites.

Temperature sensor installation was done uniformly by one person. The probes were inserted 15 cm horizontally, at the specified depths, into the south face of a 30 cm deep trench. Soil and duff were replaced in the trench in the original order. One metre north, a 5 cm x 5 cm x 1 m stake, labelled with a panel identifier and microsite number, served to identify the microsite and anchor the free end of the 2-m sensor cable.

A pair of soil moisture blocks was installed 30 cm apart, at the -15 cm depth and about 50 cm away from the previous excavation. One person uniformly installed the blocks according to the manufacturer's instructions. Leads from the blocks were taken to the microsite stake.

A terminal strip joined the sensor cables to the multiple-pair, 25-m cables leading to a data logger or multiplexer. The terminal strip was sealed inside a 15 x 10 x 10 cm plastic "Frig-o-seal" container anchored to the microsite stake. Each multiplexer was connected to a data logger with up to 50 m of 3-pair cable. All cables were buried 10 cm, with flagging tape wrapped around them every 2 m to mark location.

Data loggers and multiplexers were placed inside 20-L pails buried to the rim.

2.2.2 Fall 1985

On September 30 and October 1, 1985, thermistor probes for snow temperature were installed and wired into the terminal strip at each microsite, displacing the moisture block leads. To suspend the sensors from a 2 x 2 x 30 cm stake, they were inserted from the south through holes at 1 cm and 16 cm heights.

The sensors were not shade-protected except by the stake itself. With low sun angles and short daylight periods, direct solar radiation was not a problem. However, the sensors were probably coupled to the temperature of the stake and therefore provided a less accurate estimate of air temperature.

2.2.3 Spring 1986

Regime 3 received its complement of 30 temperature sensors on June 4–5, 1986. Installation was identical to that in the previous year except the "Frig-o-seal" container was omitted. The 2-m sensor cables were soldered to the 25-m connecting cables. The joints were sealed with heat shrink tube and silicon sealant, and buried. This hard wiring was possible because the moisture blocks were not installed. The regime 3 sensors were connected to the monitoring system via two additional multiplexers.

2.2.4 Equipment maintenance

The installation required much maintenance, especially during the 1st year. Errors in wiring or programming accounted for some data losses. Cold weather resulted in battery failure and additional losses. By the 2nd year, wiring was sorted out and programming had been standardized. To insulate the data loggers, a box of 2-inch lumber was placed over them.

A maintenance log was kept for each data logger. Programming, sensor input and data output sheets, and site visit information were filed in them. These various sheets were similar to those of Spittlehouse (1989). The logs contained many entries during the 1st year, but, as the field system was streamlined and debugged, the number of entries dropped to a level of routine maintenance.

Routine maintenance included:

1. retrieving data to tape;
2. replacing D-cell batteries and desiccant in the data loggers;
3. checking air temperature and humidity sensor outputs against an Assmann psychrometer;
4. maintaining the thermograph; and
5. altering data logger programming seasonally.

2.3 Data Handling

The type of data gathered and the methods of processing and analyzing it evolved over time. What began as an ambitious program of monitoring as many as 185 input sensors on a daily basis was reduced over time because of the difficulty in maintaining operational and reliable sensors. In particular, the soil moisture blocks and the snow temperature sensors were deleted from the program after the 1st year. These sensors are discussed below.

2.3.1 Data collection

At peak operation, early in the program, 185 inputs were read by the four data loggers on site. Depending on the season, daily records were generated for:

- average soil temperature for each of 108 probes (°C)
- average snow temperature for each of 72 probes (°C)
- average, maximum and minimum air temperature at 1.5 m (°C)
- total rainfall (mm)
- total PAR (Einsteins/m^2 per day)
- average wind speed (m/sec)
- minimum relative humidity and air temperature at the minimum
- soil moisture for each of 72 moisture blocks.

With the elimination of the soil moisture blocks and snow temperature sensors, the number of sensors regularly monitored shrank to less than 120. The data logger storage capacity was never fully used between site visits, which ranged from every few weeks to several months.

2.3.2 Data processing

Data processing and analysis developed with experience. While the methods changed, the production of weekly soil temperature means by regime and MSP, and of weekly or daily meteorological values, was consistent. These are statistically "good" variables as described by Robertson (1989), being free from auto-correlation and seasonal cycles. In the end, processing was done with a CSI PC201 computer card and PC206 software to produce ASCII datasets. These were summarized with SAS[4] PC software.

An important step in the data processing involved a manual editing of daily values of all sensors in each panel. This was required because intermittent problems with sensors were not uncommon (see Section 3.1). Rather than an offending sensor being deleted entirely, it was compared with its panel neighbours on a daily basis. This subjective editing, comparing temperature trends between microsites and depths, was found to be an effective and reliable means of identifying and eliminating bad data. Data between panels were never edited in this fashion.

3 RESULTS AND DISCUSSION

This section relates results in three categories: equipment operation, environment monitoring, and seedling performance.

3.1 Equipment Performance

The ability to generate a reliable data base depends on several factors: a good system design, well operated; reliable equipment; and luck. Overall, the Stewart Lake installation was successful at providing the information required, but not without problems. These included outright data losses and, in the 3rd and 4th years, erroneous soil temperature data.

Equipment performance is discussed under the three categories of data loggers, soil moisture blocks, and soil temperature probes.

3.1.1 Data loggers

The processing reliability of the data logger system was checked *in situ* during 1988. To do this, 107 probes were constructed with 249K ohm resistors in place of thermistors. Two "fixed" probes were connected from a microsite to each data logger. One was connected via a multiplexer and the other wired directly to the data logger. This provided eight cases to examine. These "fixed" probes were processed as additional 107 probe inputs, providing daily average, maximum, and minimum values. The results were encouraging in seven of eight cases. Over the entire year the temperature of five "fixed probes" did not vary; one varied 0.1°C; and one varied 0.2°C. In the worst case, a 1.0°C range was recorded. This was from a microsite with a hardwired and buried connection, routed via a multiplexer. Moisture at the buried junction was the probable cause of the wide temperature range.

3.1.2 Moisture blocks

The record of soil moisture generated over the 1985 summer was sporadic. Problems with wiring hindered data collection. The blocks were very sensitive to electrical connections and often registered values that could be duplicated in the lab when the parallel 1K ohm resistor was disconnected (D. Spittle-

[4] SAS is a trademark of SAS Institute Inc.

house, pers. comm.). Since the problem could not be alleviated, one member of each pair of blocks, at each microsite, was disconnected from the system and read by hand with a Soilmoisture Corporation 5201 meter, five times during the season. All blocks were to be read by hand in 1986, but physical damage, probably caused by freezing action, rendered most of them unreadable in the spring of 1986. They were eliminated from the system.

Can moisture blocks be relied on to produce good data? Even given a solution to wiring difficulties, there are other questions. Although the units can apparently generate a good data base of resistance over time (D. Spittlehouse, pers. comm.), data interpretation is difficult since calibration is fairly broad and conclusions are restricted to conditions of "wet" or "dry." Additionally, soil-to-block contact in the dry range is often suspect and response time is slow. Moisture blocks should be used in conjunction with more labour-intensive soil psychrometers or gravimetric sampling.

3.1.3 Soil temperature sensors

The reliability of soil temperature data deteriorated over time. This was observed, especially in the 3rd and 4th years, as daily data that looked unreasonable for the given treatment and time of year. Specific examples include a sensor that showed little annual fluctuation; a group of three microsite sensors that showed incorrect relative temperatures on a daily or annual basis; and a sensor that occasionally registered as an open circuit.

This problem of "bad" data was very difficult to deal with. In the interest of producing a reliable soil temperature record over time, all daily data from all sensors were manually edited as described in Section 2.3.2. The cause of this data deterioration is not clear. In cases where sensors were run directly from microsite to data logger or multiplexer with buried, hardwired connections, moisture infiltration was a likely cause. For sensors routed via a terminal strip, corrosion on the terminals or shorting may have been the problem.

These problems of circuit continuity were aggravated by the high-resistance thermistors that CSI uses in its probes. High impedance in the sensor circuit heightens the potential for current leakage from the circuit and interference of other bridging resistances. Lower resistance values would result in more robust field systems, but at the expense of greater power demands.

The monitoring system was removed in the fall of 1989. Condition of the buried sensors was excellent, with no visible deterioration of the cable insulation or potting resin. All buried cables also showed no damage except at splices protected by heat shrink tubing and silicon sealant. The sealant had degraded and separated from the cable, making moisture infiltration possible. A second problem area was at the terminal strip junctions in "Frig-o-seal" containers. Insulation deteriorated by exposure to sunlight; white leads suffered the least damage. While many leads showed bare wire, the configuration generally prevented any of these from shorting.

3.2 Environment Monitoring

In characterizing the environment, results are discussed under three topics: weather, soil bulk density and moisture; and soil temperature.

3.2.1 Weather

Air temperature and precipitation are two major weather elements that greatly affect growing season productivity. The monthly patterns of precipitation are shown in Table 2. Three of the four years received average rainfall over the growing season; 1987 was very wet. More important than seasonal totals is the distribution. The year 1985 was very dry, with infrequent but heavy precipitation (e.g., daily rainfall >40 mm). Significant rainfall did not occur until mid-August. June and August were dry months in 1986; 1988 showed an average distribution of rainfall.

TABLE 2. Monthly growing season precipitation (mm) from 1985 to 1988

	Precipitation (mm)				
	1977–1984	1985	1986	1987	1988
(Sunset Prairie)					
May	37	a	a	>40	53
June	68	21	0	77	83
July	72	8	84	193	57
August	56	64	7	184	33
September	35	131	103	8	10
Totals	268	≥224	≥194	>502	236

[a] Indicates missing data.

Characterizing growing season air temperature year to year is more difficult, but the timing of killing frosts (<-2°C) is significant. Late spring or early fall frosts were not a factor in any year as measured in one replicate at 1.5 m. Early May was the usual date of last frost, well ahead of shoot extension. Fall frosts usually occurred in mid-September, by which time buds appeared resistant. Figure 6 shows air temperature at 1.5 m during the 1985 growing season, indicating the diurnal and seasonal range. Excessive air temperatures were generally uncommon, but occasional cooling to near zero did occur during the season.

Winter weather conditions were much more rigorous. Snow depth is typically shallow and repeated thaw conditions often leave seedlings exposed during subsequent severe cold periods. In 1985, seedling exposure was inferred from temperature data collected at two-thirds seedling height (16 cm) and at 1 cm. Seedling exposure and intensity of site preparation were positively correlated. Exposure was least in rake panels and most in plow panels. Snow levels were generally less than 16 cm in all treatments but occasionally exceeded that depth in the rake treatment. Two warm periods reduced snow levels to near zero. Outbreaks of arctic air (-30°C) coincided with low snow levels on two occasions. The winter 1985/86 pattern of daily extremes is shown in Figure 7a. A more complete temperature trace is available for the winter of 1986/87 (Figure 7b). The following two winters were of the same character.

3.2.2 Soil bulk density and moisture

Bulk density was sampled over the four MSP treatments. Three replicates from four panels were taken, centred at 15 cm of mineral soil. Bulk density was statistically different by treatment, ranging from 1.32 g/cm^3 for the brush rake to 1.63 g/cm^3 for the disk. Since this sample was limited, the results merely indicate conditions rather than explaining the causes for the differences.

Information from the soil moisture blocks in 1985 was not conclusive. When a reasonable record could be examined, great variability from microsite to microsite within a treatment and also between moisture blocks at the same microsite was typical. Statistically significant differences between treatments were not found.

Because of the poor performance of the moisture block system in the previous year, a schedule of gravimetric sampling was used in 1986. Sampling was restricted to three panels of major interest:

1. winter shear with herbicide
2. winter shear without herbicide
3. plowed with herbicide

Comparison of the first two indicates the effect of herbicide on soil moisture in the absence of cultivation; the third samples the most intensive site preparation treatment. Comparison of the first and third panels indicates the effect of major cultivation on soil moisture in the absence of vegetation. Samples were taken from the top surface of mineral soil with a 67 x 98 mm (height x diameter) sleeve. Table 3 shows the gravimetric moisture content of the three panels on three dates in the summer of 1986.

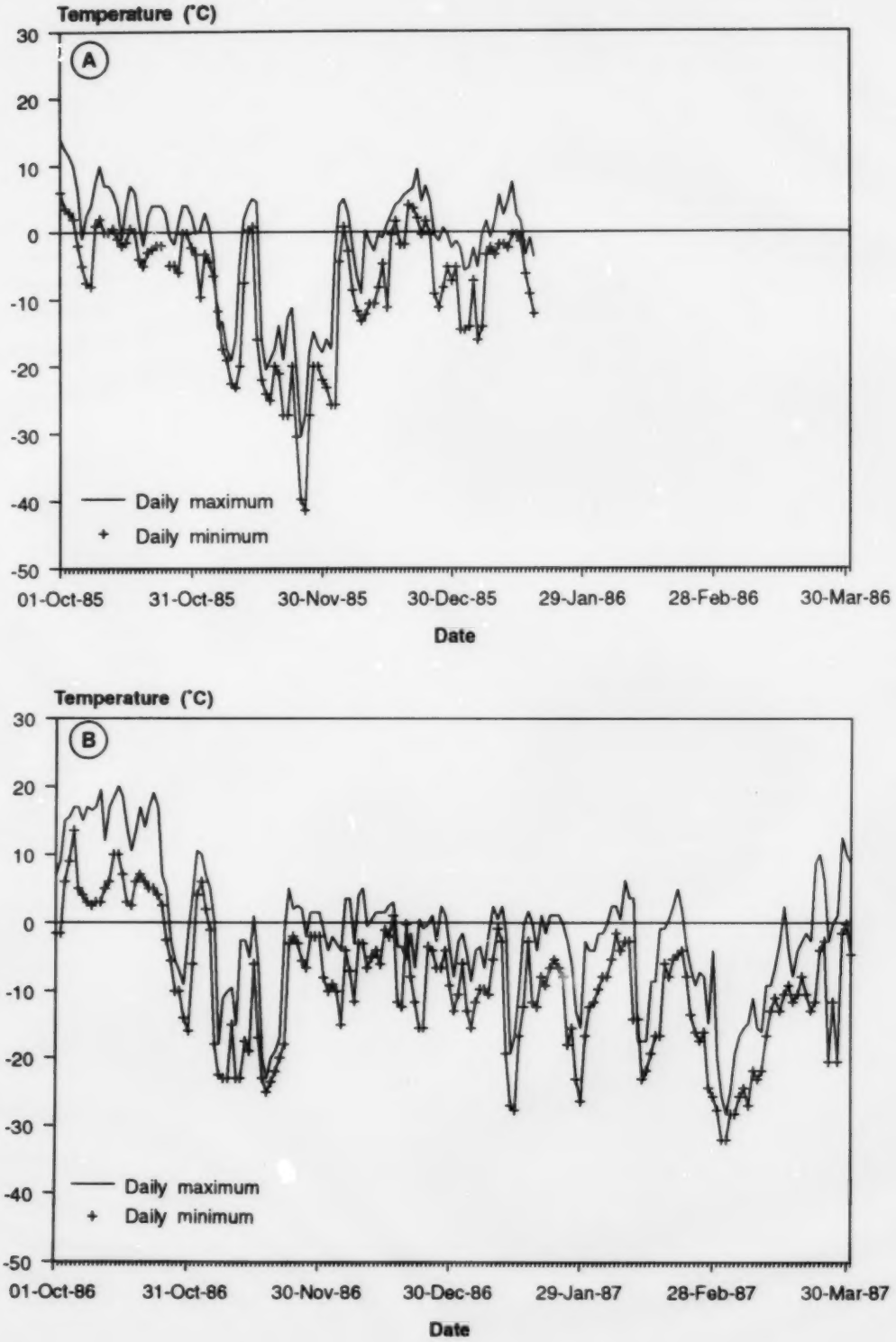


FIGURE 7. Daily maximum and minimum air temperatures at 1.5 m for: (a) early winter 1985/1986 and (b) winter 1986/1987.

TABLE 3. Gravimetric soil moisture content (%) for three treatment combinations on three dates in 1986

Date	Soil moisture content (%)		
	Shear/no herbicide	Plow/herbicide	Shear/herbicide
June 4	32	20	32
July 3	21	10	31
August 26	5	9	24

The plow treatment was low, decreasing from 20 to 9% over the season. Better drainage reduced the content early and, in combination with surface slope, recharge following precipitation was not substantial. Comparing the shear treatments shows the dramatic effect of competing vegetation on soil moisture. Early in the season, moisture level was higher than the plow treatment as a result of the level, organic surface of the shear panels. This was a factor in depressing their soil temperatures. Soil moisture was lost by evapotranspiration on the unherbicided panel as the season progressed. By late August, content was lower than in the plow treatment, and both were much lower than in the herbicided panel which remained moist all season.

Soil moisture content was not closely monitored during the following growing seasons.

3.2.3 Soil temperature

Soil temperature exhibited a consistent annual pattern over the 4 years, varying in absolute scale with annual weather differences. Relative treatment differences decreased through time as a result of vegetation development. The 1985 and 1986 data, for example, illustrate the annual pattern and treatment effects.

The herbicide treatment effects of regimes 1 and 2 did not differ in 1985, so data were combined, providing six temperature estimates for each MSP treatment. Weekly mean soil temperature at -5 cm is presented in Figure 8. Each treatment exhibits a thermal regime distinct from the others. As temperatures warmed during the summer, ranking was maintained and differences increased. An isothermal period in the fall was followed by winter temperatures in the reverse order.

An anomaly occurs in Figure 8 for the plow treatment in the fall. An explanation for the sharp drop of the plow soil temperature may be that the raised microsites in the plow panels were dry and had little heat capacity compared to other panels. As a result, the microsites cooled greatly.

The diurnal and seasonal pattern of soil temperature is a function of the weather, microsite aspect, and the thermal properties of the soil. In a given year, the temperature differences observed over the experiment site are attributable to soil thermal properties, with aspect being an important factor in the plow treatment.

Chang (1968) identifies two major thermal properties of soils: heat capacity and thermal conductivity. A high heat capacity results in cooler soil temperatures because much energy is required for a small temperature increase. Moist soils have a high heat capacity and are slow to warm up. A low thermal conductivity (i.e., good insulation) results in a strong temperature gradient through depth. An organic layer has a low conductivity and results in high surface temperatures with cool subsurface temperatures. In general, the temperature of soils with a mineral surface is tied to solar radiation and may show wide daily variation. The temperature of soils under an insulating layer, however, are tied to air temperature, with variation occurring on a seasonal scale.

Thus, the 1985 summer soil temperatures can be explained in terms of the characteristics of the various treatments.

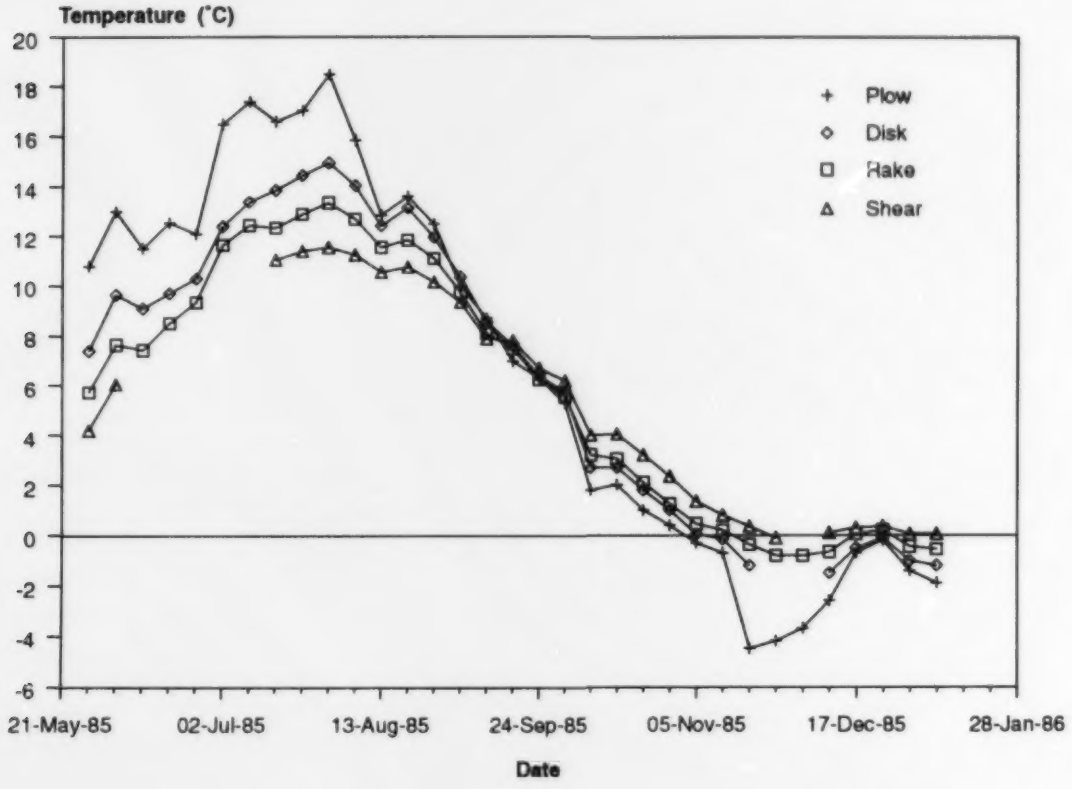


FIGURE 8. Weekly mean soil temperature at 5 cm depth by treatment for 1985.

The plow treatment is distinguished from the others by its convoluted, exposed mineral surface. This results in a low heat capacity (good drainage) and high conductivity (mineral soil). These factors make the plow treatment the warmest during the summer months, especially on sunny days, and the most responsive to weather changes.

The shear treatment is the coolest because the organic layer is virtually undisturbed and much radiation is blocked from the surface by residual and suckering aspen.

The rake and disk treatments display similar temperatures. The additional disturbance of disking disrupts the surface organic matter, allowing warm air and radiation to penetrate the surface. This causes the disk treatment to warm slightly more than the rake treatment.

Rainfall affects soil temperature by several mechanisms. Incident radiation is reduced because of cloud cover, and surface evaporation consumes energy, resulting in less energy to heat the soil. A temperature drop is expected following precipitation, especially if it is sufficient to moisten the soil. The increased heat capacity means slower rewarming and the increased conductivity results in more uniform temperature through depth. The onset of the isothermal period in late August (Figure 8) was possibly premature and likely brought on by the heavy precipitation at the time.

Analysis of variance of the 1985 temperature data at three points in the season shows the empirical differences between the treatments (Table 4). Means were compared using Fisher's unprotected least significant difference (LSD) test. The LSD values indicate that variability between microsites, within a treatment, is reduced as the soil system acquires its summer profile. Generally, a temperature difference of 2° characterizes a significant treatment effect.

TABLE 4. Weekly mean soil temperature at three dates in 1985, compared using Fisher's unprotected least significant difference tests at Alpha=0.05. Means followed by the same letter are not different.

Date	Treatment	Depth					
		5 cm	N	15 cm	N	30 cm	N
May 28, 1985	01	10.80a	6	8.90a	6	4.90a	5
	02	7.40b	6	6.20b	5	4.70a	6
	00	6.10bc	5	6.20b	5	4.00a	5
	03	5.30c	5	4.00b	6	3.00a	5
	LSD	2.10		2.30		2.70	
	MSE	2.70		3.33		4.36	
June 4, 1985	01	13.00a	6	11.30a	6	7.30a	6
	02	9.60b	6	8.50b	5	7.10a	5
	00	8.00bc	5	6.80bc	5	5.90a	5
	03	7.20c	5	5.90c	6	4.80a	5
	LSD	2.30		2.40		2.90	
	MSE	3.22		3.64		5.00	
July 30, 1985	01	18.50a	6	17.20a	6	14.50a	6
	02	14.90b	6	14.30b	6	13.20ab	6
	00	13.70b	5	12.70c	5	11.80b	5
	03	11.50c	5	10.70d	6	10.10c	5
	LSD	1.70		1.50		1.60	
	MSE	1.86		1.54		1.54	

The July 30 data show that treatment differences were the greatest when the soil reached its summer maximum temperature. The May 28 and June 4 data are of interest since this was the time of planting. If 5°C is accepted as the lower limit of root growth, the plowing treatment created a favourable temperature environment for the newly planted seedlings. This temperature advantage continued throughout the growing season, but root growth following shoot extension may have been limited by drier soil late in the season.

Maximum soil temperatures in 1986 occurred in the week of August 13. Table 5 summarizes that data by regime, treatment and depth. The soil temperatures were compared by regime (Table 6) and by treatment (Table 7) at the three sensor depths. Regime and treatment were significant, and there was no regime/treatment interaction at p=0.05. Ranking of soil temperature in the four treatments remained the same between 1985 and 1986, but maximum values and treatment differences decreased chiefly because of cooler weather and changes in the vegetation cover.

Vegetation effect on mean temperature was most dramatic on the shear treatment panels. Heavy suckering of aspen and willow increased the cover in regime 1 from 46 to 71%; regime 2 cover was reduced from 48 to 23% by herbicide. As a result, regime 2 mean soil temperature at 5 cm was 2°C warmer than in regimes 1 and 3. The difference was 1.5°C at 15 and 30 cm. The LSD values of 1.3, 0.7, 0.8°C at 5, 15 and 30 cm indicate that the lower depths were less variable and therefore more useful in distinguishing regime differences.

The lack of significant difference between regimes 1 and 3 is encouraging, indicating that sensor installation is repeatable from one panel to another. These regimes had received the same treatment to this point, but differed by year of sensor installation.

Daily temperature fluctuations at -5 cm depth are illustrated in Figure 9. These data were recorded on a clear day in early July 1986, when the maximum air temperature reached 16°C at 14:30 PST.

Maximum and minimum soil temperatures were strongly affected by both the herbicide and the MSP. The presence of only 20% vegetation cover on the non-herbicided, plow treatment was sufficient to depress the maximum by 3°C from the herbicided plow treatment. A 70% cover on the non-herbicided shear treatment depressed the maximum by 5°C from the herbicided shear treatment. A 6°C gain was seen on the plowed treatment, compared to the shear treatment in the absence of vegetation. This gain

can be attributed to the improvements in the aspect, drainage, and mineral soil exposure of the plow treatment. With vegetation intact on the shear treatment, the maximum temperature was 10°C compared to 21°C achieved with plowing and herbicide.

TABLE 5. Treatment mean and standard deviation of soil temperature (°C) for the week of August 13, 1986, by depth and regime

		Regime					
		1		2		3	
	Treatment	Mean	SD	Mean	SD	Mean	SD
5 cm	01	16.3	1.59	17.8	0.90	16.3	1.59
	02	14.1	0.80	15.2	1.00	14.3	1.16
	00	13.1	0.23	13.9	0.90	12.3	0.20
	03	11.9	1.76	15.1	3.67	11.1	0.10
15 cm	01	15.5	1.39	17.2	0.17	15.5	1.39
	02	13.8	0.91	15.1	0.95	13.8	1.45
	00	12.7	0.35	13.8	0.47	11.9	0.35
	03	11.3	0.23	12.8	0.79	10.9	0.12
30 cm	01	13.8	1.45	15.9	0.86	13.8	1.45
	02	12.9	0.49	14.2	1.03	13.3	0.31
	00	12.1	0.61	14.0	0.52	11.6	0.31
	03	10.7	0.58	11.6	0.78	10.5	0.21

TABLE 6. Regime mean soil temperature (°C) for the week of August 13, 1986, compared using Fisher's unprotected least significant difference tests at Alpha=0.05. Means followed by the same letter are not different.

	Mean soil temperature (°C)					
Regime	5 cm	N	15 cm	N	30 cm	N
2	15.50a	12	14.70a	12	13.90a	12
1	13.60b	12	13.30b	12	12.30b	11
3	13.50b	12	13.10b	12	12.30b	12
LSD	1.30		0.70		0.80	
MSE	2.19		0.78		0.80	

All the factors that result in temperature gains on a sunny day contribute to losses at night. Bare mineral soil with no vegetation cover rapidly re-radiates heat at night. In comparison, the heavily vegetated and insulated shear treatment loses little heat during the night. This simple diurnal relationship can be applied to an annual scale. The plow treatments warm sooner and higher in the summer, but cool more quickly and lower as winter approaches.

Data from 1987 and 1988 are consistent with the site preparation effects and the influence of increased vegetation cover. Problems with sensor performance prohibit discussion of quantitative results, but the trends generally are the same.

TABLE 7. Treatment mean soil temperature (°C) for the week of August 13,1986, compared using Fisher's unprotected least significant difference tests at Alpha=0.05. Means followed by the same letter are not different.

Treatment	Mean soil temperature (°C)					
	5 cm	N	15 cm	N	30 cm	N
01	16.80a	9	16.10a	9	14.50a	9
02	14.50b	9	14.20b	9	13.50b	8
00	13.10c	9	12.80c	9	12.50c	9
03	12.40c	9	11.70d	9	10.90d	9
LSD	1.40		0.90		0.90	
MSE	2.19		0.78		0.80	

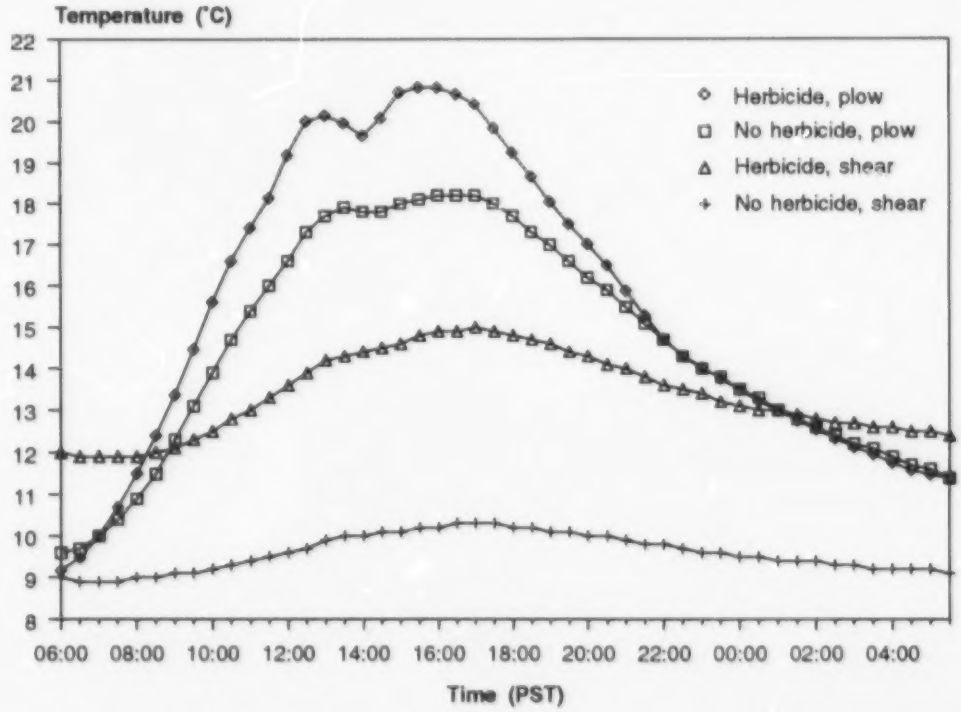


FIGURE 9. Daily soil temperature fluctuation at 5 cm depth in four panels on July 3–4, 1986.

3.3 Seedling Performance

This section discusses the performance of planted 1+0 plug stock with regard to three categories: overwinter injury, seedling growth, and competing vegetation. Information is drawn from Herring *et al.*[5] In general, the planted lodgepole pine is performing well. It appears to have quickly adapted to the site. The spruce encountered establishment difficulties, suffering high rates of overwinter damage. Spruce growth trends over the first 3 years are presented.

[5] Herring, L.J. and R.A. Letchford. 1987. Assessment of treatment options for rehabilitation of NSR backlog in the Boreal Region of B.C. EP 986.00. Establishment report No. 2, Experimental Phase 1. B.C. Min. For., Research Br., Victoria, B.C. Unpublished report.

3.3.1 Overwinter Injury

A very high rate of overwinter damage was recorded when seedlings were assessed in the spring of 1986. Dieback affected a portion or all of the main shoot, or seedlings died. About 75% of white spruce suffered damage; 28% of lodgepole pine were damaged. Damage to pine did not vary by site treatment, but spruce showed varying rates. Spruce seedlings on plow treatments sustained 60% damage compared to an average 80% damage on the other site preparation treatments. The lack of improved survival on shear treatments, where snow level was greatest, contradicts other common observations that seedlings under adequate snow cover generally survive the winter well. In this winter, snow level was relatively low all season and completely gone on two occasions. Thus, snow level may have had little influence on survival by being below a critical minimum depth on all treatments. Also, information as to the time injury occurred is lacking and makes it difficult to correlate injury and snow depth.

The positive correlation between survival and caliper increment suggests that seedlings on the plow treatment, which grew best, were less stressed and better prepared for the rigours of winter.

White spruce was replacement planted in 1986. These seedlings were also heavily damaged over their first winter. Seedlings that survived the first winter were not damaged in the second winter. The cause of damage is unknown, but freezing injury rather than desiccation is the favoured explanation. Current research on this and similar sites (FRDA Projects 1.02 and 1.41) is addressing this winter injury problem.

3.3.2 Seedling growth

The diameter growth of undamaged white spruce over a 3-year period on the plowed versus the rake treatment is shown in Figure 10. After the first growing season, survival, height and diameter were not statistically different by treatment or regime. This indicates the typical nursery culture effect the first season after outplanting. Only seedlings not injured in the winter were analyzed in subsequent years. For spruce, the average cell size was down from 50 to 11. Seedling growth was less in the 2nd year than in

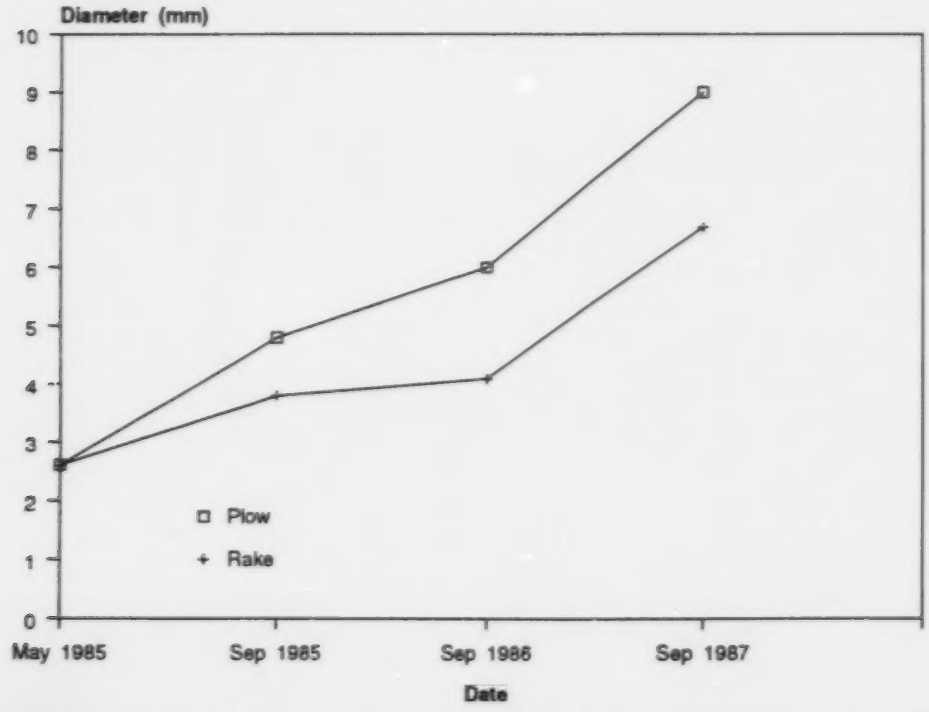


FIGURE 10. Response of white spruce seedling diameter in two site preparation treatments over three growing seasons.

the previous. Height was not affected by site preparation treatment, but caliper was. Seedlings on the plow treatment had the greatest increases, while the other three treatments had less. In the third season, growth rates increased, indicating that the seedlings were well established. The herbicide brushing and weeding of regime 3 the previous season resulted in a 30% increase in caliper growth over all site preparations, compared to the other two regimes. Height growth was not affected by the treatment (Herring 1989).

After three growing seasons, the advantages to seedlings in the plowed panels are apparent. Warmer soils and higher light levels, because of decreased competition, have offset any temporary disadvantage of less available moisture. The increasing level of vegetation competition in the other treatments can be expected to affect those seedlings through low light and soil temperatures and less available moisture.

3.3.3 Competing vegetation

Bluejoint (*Calamagrostis canadensis*) and trembling aspen (*Populus tremuloides*) are the most aggressive competitors on the site. Figure 11 shows the encroachment of vegetation over time. The plow treatment provided the best control of grass over the first 2 years and was as effective as the disk treatment in controlling aspen. The effects of herbicide are not readily apparent in this figure. Changes from 1985 to 1986 in % cover and height, averaged over control and herbicide regimes (regimes 1 and 2), were relatively small. Large increases in % cover and height occurred over all treatments in 1987, because vegetation recovery on herbicide regime 2 and on control regime 1 outweighed the suppression on herbicide regime 3. The brushing and weeding application in the 2nd year (regime 3) provided better control of aspen than when applied in the first growing season.

4 SUMMARY

This project was established in 1984/85 to examine hardwood site rehabilitation in the Peace River area on a site near Dawson Creek. The study's major objectives were to examine seedling and the vegetation community response to mechanical and chemical site preparation.

The environmental monitoring component of the project was established to provide weather data and to characterize treatments by soil moisture and temperature. Temperature data were gathered from one replicate of the 12 treatment combinations. Weekly mean soil temperature data from the first 2 years allowed comparison of soil temperature trends and statistical analysis of treatment differences. A temperature difference of 2°C characterized a significant treatment effect. Temperature variability between microsites within a treatment decreased as the soil acquired its summer temperature profile.

The plow treatment resulted in the warmest soils during the growing season; the shear treatment was coolest. During the warmest week in 1985, the weekly mean temperature at -5 cm in the plow treatment was 18.5°C; the shear was only 11.5°C. Data for the comparable time in 1986 showed the effect of vegetation removal by herbicide. Temperature at -5 cm averaged 2°C higher over all site preparation treatments where herbicide was applied.

Data problems related to sensor construction limited the interpretation of information in the 3rd and 4th years. Data from the 5th and final year of the monitoring component are still to be reported. Soil moisture data gathered from gypsum blocks were of little use in distinguishing treatment differences.

Lodgepole pine and white spruce were planted on the site. A major difference between them was the ability to survive the first winter. About 75% of white spruce and less than 30% of lodgepole pine were damaged over the 1985/86 winter. Seedlings that survived the first winter were not damaged the next. Growth data analysis was limited to undamaged seedlings. Growth and survival of white spruce was best on the plow site preparation treatment.

Combinations of herbicide and site preparation treatment produced different effects on the two main competitors, aspen and bluejoint. The plow treatment provided the best control of grass, and was as effective as the disk treatment in controlling aspen. Herbicide was most effective against aspen when applied in the second season after site preparation.

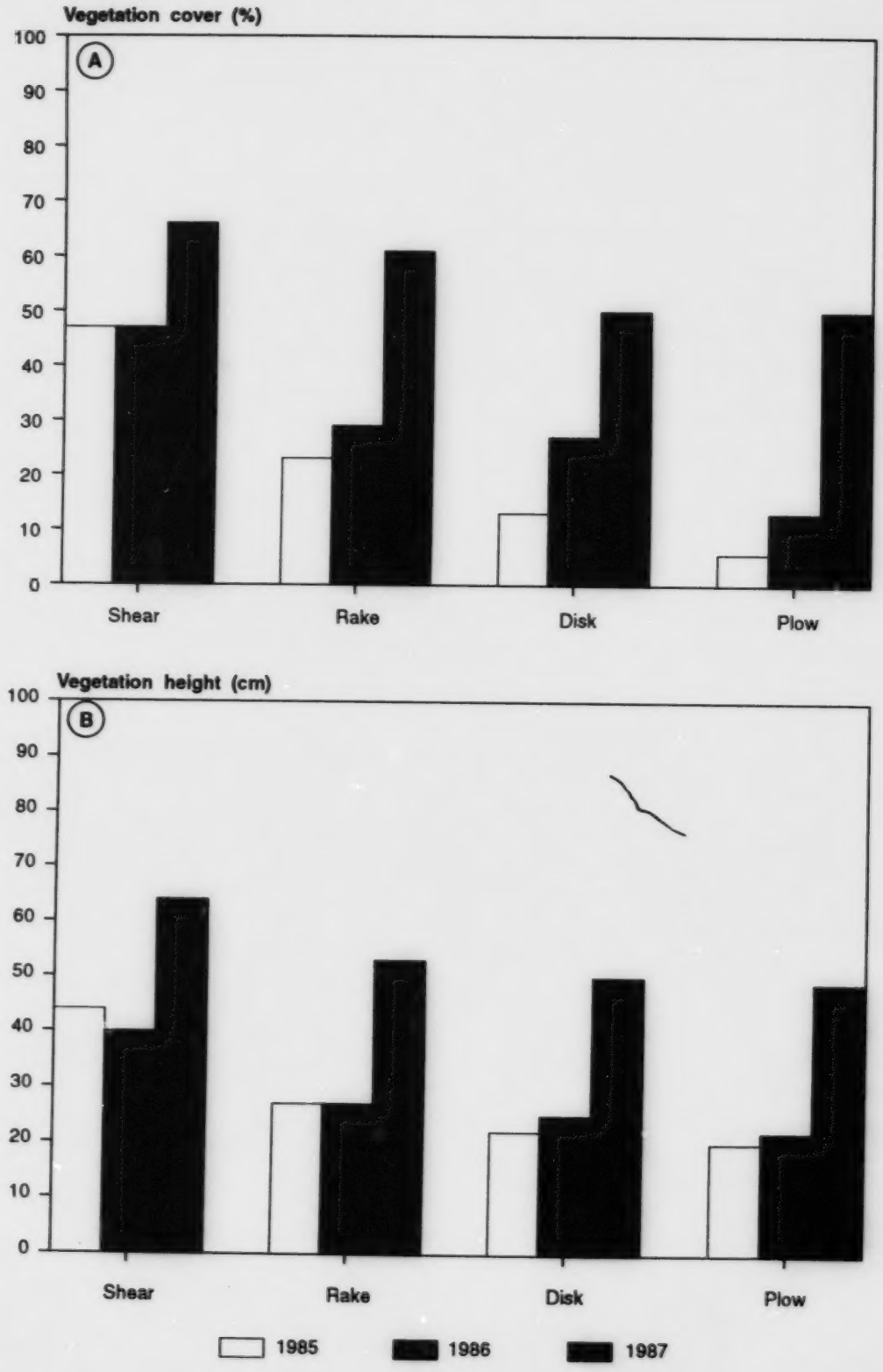


FIGURE 11. Vegetation development over 1985–1987 by site preparation treatment as (a) percent cover and (b) height.

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Queen's Printer for British Columbia©
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